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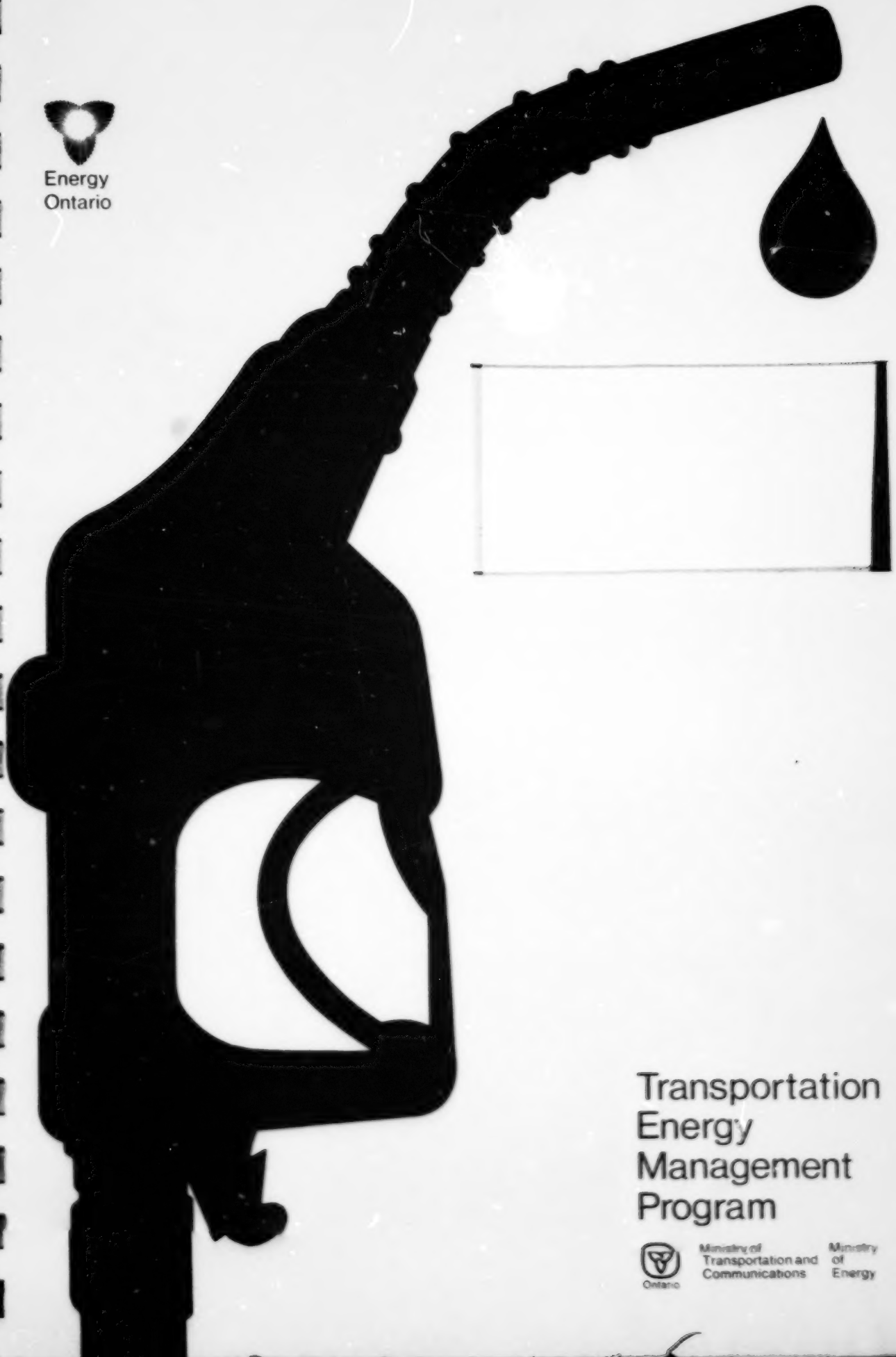

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Demonstration of CNG Utilization in Private Sector Fleets

-Final Report-

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Prepared by
The Consumers' Gas Company Ltd.
Research and Special Projects Division

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Abstract:
This paper reports on the observations and analysis of the two-year program undertaken by Consumers' Gas, i.e., the utilization of CNG in private sector fleets. Problems, advantages and disadvantages of the conversion were specified. Prospects were also looked into.

Key Words: CNG, conversion, fleet, consumption, refuelling

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EXECUTIVE SUMMARY

Following a number of economic feasibility studies and the announcement that the Ontario road tax would be eliminated for any alternative-fuelled vehicle, Consumers' Gas proceeded with plans to demonstrate the feasibility of using natural gas as a transportation fuel.

Funding support was secured from the Ontario Ministry of Transportation and Communications under the auspices of the bilateral Federal/Provincial Conservation and Renewable Energy Demonstration Program, and the project was initiated in March 1981.

By September 1981, 22 Consumers' Gas service vans had been converted to operate on dual fuel, natural gas/gasoline basis and complete refuelling facilities were installed at their base of operations near downtown Toronto.

Total expenditures were estimated at approximately $162 000 including materials and labour for vehicle conversions and compressor/refuelling plant. All work was carried out in-house for reasons of economy and in order to provide hands-on experience with the equipment and concepts.

Detailed monitoring of compressor station, natural gas fleet, and gasoline-powered control fleet continued over a 12-month period, with ongoing results documented through regular progress reports.

Natural gas fuel consumption figures were calculated through elaborate computer analyses resulting in daily and monthly statistics for individual vans, as well as detailed comparative summary charts relating natural gas and gasoline use.

Over the first year of operation, it was determined that the natural gas-powered fleet operated 85% of the time on gaseous fuel, using gasoline for backup only on rare occasions. The 22 vans covered nearly 210 000 km and used almost 61 000 m^3 of natural gas for a total fuel cost (gas plus

electricity) of $8200. The average operating cost, including backup gasoline use, was 5.29¢/km.

In contrast, the gasoline group used over 61 000 L of gasoline costing $23 250 to travel 196 800 km, at an average operating cost of 11.81¢/km. Thus, saving realized with the natural gas fleet was roughly 6.52¢/km. Considering the total distance driven in the first year, fleet saving was nearly $16 000 over what gasoline would have cost -- an average saving of $730/van.

It was determined that 0.93 m^3 of natural gas (32.83 cu ft) would provide the same range as 1 L of gasoline. However, the fuel cost was only 12.58¢, whereas gasoline was retailing for an average of 38¢/L. These figures are the same as 4.23 m^3 (149.42 cu ft) of natural gas per Imperial gallon of gasoline, at a price of 57.22¢ as opposed to $1.73. Approximately 7% of total fuel price is attributed to electricity charges for running the compressor.

Consumers' refuelling facility was the only source of high-pressure gas in Ontario throughout the demonstration period, such that a heavier-than-anticipated demand was placed on the station by various CNG promoters as well as those with their own trial vehicles. As a result, total station throughput was 68 000 m^3 (2400 Mcf) in the first 12 months.

As could be expected, the demonstration was not without its problems. Over the course of the project, mechanical difficulties experienced with the vehicles were, for the most part, limited to frequent check valve failures, although minor annoyances like; hard-starting in cold weather, impaired acceleration and handling, and clogged regulator filters were also documented.

An intensive oil monitoring program concluded that oil drain intervals may be extended up to twice as long with the Ford vans, but silica contamination consistently restricted oil-life in General Motors products to the same as for gasoline.

Much like the oil analysis situation, natural gas emissions seem to be somewhat related to vehicle manufacturer. Nitrous oxides tend to be reduced, but unburned hydrocarbon levels increase for both Ford and GMC vans. However, carbon monoxide levels were found to decrease remarkably for the GM van, and increase significantly for the Ford product. The MTC concluded that different vehicles using similar conversion hardware resulted in notably different operating and emissions characteristics.

For the most part, the compressor and refuelling station performed in an acceptable manner with a high degree of reliability, although several modifications were required. Piston blowby in the compressor resulted in lubricating oil entering the high-pressure gas stream. A special separator had to be added on the compressor outlet, while an auxiliary reservoir was incorporated to serve the crankcase. All 28 flexible drop hoses on the slow-fill line have been replaced three times due to minor gas permeation problems, and a check valve on the compressor had to be replaced. In addition, the quick-fill storage system has operated only occasionally in the proper automatic sequential cascading mode. Finally, a dome-loaded regulator was retrofitted to the system, thereby providing the quick-fill cascade with 24.8 MPa (3600 psig) gas while limiting the slow-fill process to the temperature-compensated equivalent of 20.7 MPa (3000 psig).

The conversion of 12 large construction trucks to operate on natural gas is expected to bring the compressor facility closer to its design capacity. From the outset, it was recognized that the station was unarguably oversized for the vans alone, but the addition of these 12 trucks is comparable to adding 24 vans as far as increased gas load is concerned. A detailed economic analysis for the larger fleet based on a comprehensive net present value treatise shows a positive cash flow situation in year eight.

Operating data and performance results derived from the demonstration program have been used in exhibits and special presentations in order to increase overall awareness of the natural gas option. Other information

transfer schemes, specifically tailored to accomplish this objective in both commercial and public sectors, were brought into effect during the summer of 1983.

It is concluded that Consumers' two-year demonstration has indeed made an important and valuable contribution to efforts aimed at establishing natural gas as an alternative motor vehicle fuel in Canada, and that many of the objectives put forward in the original program proposal have been duly accomplished.

1/ INTRODUCTION

In January 1980, the Research and Special Projects Department of Consumers' Gas Company Ltd. completed a number of economic studies which indicated that compressed natural gas as a vehicle fuel could indeed be a viable alternative to gasoline. However, economic feasibility repeatedly proved to be highly dependent upon alleviation of provincial road tax.

A submission was sent to the Ontario Ministry of Energy stating that Consumers' was prepared to demonstrate CNG technology, providing the province would eliminate the road tax which would otherwise be applied to natural gas used for this purpose.

In April of 1980, the Hon. Frank Miller, then Treasurer of Ontario, announced that any alternative-fuelled vehicle, be it CNG, propane, methanol, electric or whatever, would be fully absolved from paying the 4.7¢/L road tax. As a result, Consumers' proceeded with plans to mount a CNG-powered fleet vehicle project.

It soon became apparent that the terms of reference and objectives of the project were directly in line with those of the bilaterial Federal/Provincial Conservation and Renewable Energy Demonstration Program, and a complete proposal was duly submitted to the appropriate Management Committee.

Ensuing discussions culminated in a contract administered by the Ontario MTC wherein Consumers' Gas agreed to carry out a demonstration of the technology and economics of CNG utilization as a transportation fuel for commercial fleet vehicles, and to assess the market applicability of CNG as a transportation fuel in Ontario.

By mid-September 1981, 22 Consumers' Gas service vans had been converted to dual fuel CNG/gasoline, and complete compression/refuelling facilities were installed at their base of operations at 405 Eastern Avenue near downtown Toronto.

Monitoring of both compressor station and CNG fleet performance was initiated on October 1, 1981 and continued for one full year, terminating on September 30, 1982.

A descriptive report concerning vehicle conversions and complete refuelling station design and specifications was submitted early in the program, followed by three consecutive progress reports which detailed findings over three- to four-month periods.

Presented herewith is a summary of the 12-month demonstration program highlighting vehicle operating data and costs, overall saving, refuelling station economics, mechanical and technical problems and solutions, as well as general market genesis and forthcoming developments.

2/ VEHICLE CONVERSION AND COMPRESSOR STATION DETAILS

As already mentioned, 22 gas fitters' vans consisting of eight Ford Econolines and 14 Chevrolet VanDuras were converted during August 1981 to operate on a dual fuel gasoline/CNG system (Appendix 1).

Prior to selecting equipment, extensive information was procured regarding technical data, prices and availability of the various components on the market. A number of working CNG installations were visited, taking special note of specific problems experienced by established users.

Although several organizations who specialized in CNG technology were consulted, it was decided that Consumers' would benefit two ways by doing all aspects of the work in-house. Firstly, hands-on experience would enable key individuals to be intimately familiar with the equipment and installations. Secondly, it was shown that the cost estimates of doing the work in-house were significantly lower than bids received from turn-key type organizations.

For these reasons, conversion kits were ordered from one supplier, while cylinders, fittings, tubing, compressor, etc, all came from others.

2.1/ Vehicle Conversions

As shown in Figure 1, after-market vehicle conversion to dual fuel CNG/gasoline is fairly straightforward, although a somewhat unique approach was taken with regards to on-board fuel storage.

Each vehicle was equipped with two high-pressure cylinders mounted vertically behind the drivers' seat, but inverted such that the cylinder shut-off valves protrude through the floor of the van. In this way, all potential leak sites (valves, tubing connections, etc.) are outside the passenger compartment.

Measuring 235 mm O.D. and 1300 mm long (9.25 x 51"), combined fuel capacity is roughly 23 m^3 (800 cu ft) at 20.7 MPa working pressure and 21°C (3000 psig and 70°F).

A number of range tests repeatedly indicated that each fill would be sufficient for approximately 90 to 115 km (60 to 70 mi) depending on end-of-fill pressure and temperature conditions.

High-pressure delivery lines leading from the cylinders to the conversion kit located in the engine compartment are 3/8" seamless stainless steel tubing.

Supplied by Alternative Fuel Systems of Windsor, Ontario, the kit is based on the Tartarini reducer/regulator and an over-the-barrel type air/fuel mixer of their own design. Other components include solenoid valves, dash mounted rotary fuel selection switch and pressure gauge, gas delivery, vacuum and water hoses, as well as all connections, clamps and electrical hardware required to complete the installation.

All conversions were carried out by company mechanics following a training workshop conducted by the conversion kit supplier.

Following conversions, each vehicle was pressurized to 27 MPa (4000 psig) with nitrogen and checked for leaks. After filling the system with natural gas, minor modifications needed to give improved performance were accomplished using a dynamometer, after which the vehicle was placed back in service.

Overall conversions usually entailed one full eight-hour shift per van, consisting of roughly four hours of welder's time to mount the cylinders, and four to six hours of mechanic time. Average cost, including materials and labour, was approximately $1800 per vehicle.

2.2/ Compressor Station

As with the vehicle conversions, company personnel took on the task of designing and constructing the refuelling facility (Figure 2).

The workhorse of the system is the two-stage, water-cooled Norwalk compressor (Figure 3). With an inlet pressure of 1.206 MPa (175 psi) and driven by a 25-horsepower electric motor, this machine provides com-

pressed gas at the rate of 110 m^3/h (65 scfm) and fill pressures up to 25 MPa (3600 psi). A water-cooled machine was selected in preference to air-cooled models due to favourable reports from other users claiming far superior reliability with the former.

Normally, refuelling is accomplished using the slow-fill approach where all 22 vans are topped up overnight (Figure 4). The slow-fill header consists of NPS 1 seamless steel pipe, ASTM A53 Gr.B, 4.55 mm wall thickness, all welded, coated and wrapped. Located below grade at a depth of 0.61 m (24 in), the header serves seven risers which in turn support four flexible refuelling hoses. The service pressure on the slow-fill components never exceeds 20 MPa (3000 psi).

For those instances where a driver runs out of natural gas halfway through a shift, or perhaps needs more gas for overtime work, a fully automatic quick-fill storage cascade was installed which can provide a complete fill in less than four minutes (Figure 5).

This storage facility consists of 20 steel cylinders rated for 25 MPa (3600 psi) service, at which pressure it contains about 283 m^3 (10 000 scf) of natural gas.

Final installed cost of the refuelling station, including numerous valves, protective barriers, electrical hookups, and more recent additions such as oil separation and high-pressure regulation equipment, was estimated to be $122 000.

Hence, overall project implementation costs for vehicle conversions and the required compression facility were approximately $162 000.

It is important to stress that although only 22 vans were serviced by this station during the test period, the compression equipment is actually capable of serving twice this number. With the completion of the one-year demonstration, more vehicles are being adapted for natural gas operation such that optimum station utilization is expected by mid-1983.

3/ FLEET FUEL CONSUMPTION

In order to produce comprehensive natural gas fuel consumption figures, a rather elaborate monitoring and data acquisition process had to be created.

An integral part of the monitoring program was selection of an appropriate control group. To this end, a second service depot having 18 gasoline-powered vehicles with identical work duties and similar city-type travel conditions was selected.

The gasoline group was analysed for monthly travel distance, gasoline use and cost by drawing from in-house transportation department records. The natural gas group, on the other had, demanded that a new and innovative approach be taken by virtue of the uniqueness of the natural gas refuelling situation.

As opposed to gasoline vans which refuelled once or twice per week at conventional pumps with conventional billing methods, natural gas vehicles were connected to the refuelling header by the driver each and every day upon shift completion. Lack of high-pressure metering devices and the fact that all vehicles refuel at the same time over a three- or four-hour period prevented utilization of traditional custody transfer techniques. The only way to accurately assess CNG vehicle fuel consumption was to devise a completely new data procurement and analysis procedure as demonstrated graphically in Figure 6.

First of all each driver had to record the odometer reading, system pressure, and cylinder temperature at both beginning and end of each and every shift.

Consumers' Systems group created a specific computer program capable of calculating daily distances driven as well as gas volumes required to do so. The latter was accomplished through a series of complex equations relating cylinder capacity to pressures and temperatures before and after each fill-event. The direct result of computer analysis is a comprehensive month-end printout showing input data and resultant distance vs. natural gas volumes.

For the natural gas group, each vehicle's monthly distance and natural gas totals were entered on a summary sheet along with fuel and electricity costs for that month. A similar sheet summarized parallel data for the gasoline group.

Finally, a comparison chart detailing overall statistics for each fleet was prepared showing relevant operating costs, savings, and fuel equivalence calculations. Fuel equivalence is defined as the actual volume of natural gas (cubic feet or cubic metres) capable of providing the same range as 1 L of gasoline.

Table 1 is a compilation of monthly distance, fuel consumption and fuel cost figures for both the CNG and gasoline groups during the 12-month period.

Hence, the gasoline fleet travelled 196 823 km over the monitoring period and used 61 062 L at a total cost of $23 249.40. Likewise, the CNG fleet covered 209 916 km and consumed 60 621.5 m^3 (2 140 000 cu ft) of natural gas at a total fuel cost (gas plus electricity to drive compressor) of $8194.64. However, on rare occasions the natural gas supply proved to be insufficient for providing adequate daily range such that drivers had no choice but to switch over to operate on gasoline from time to time. Even though natural gas was used 85% of the time, it was necessary to add a further 32 000 km and 11 856 L of gasoline, plus $4629.05 to the test fleet statistics to account for emergency gasoline use. These additions are accounted for in the overall year-end summary chart shown as Table 2.

Thus, the CNG group, in reality, covered 241 916 km on $12 823.69 worth of natural gas plus gasoline, for an average operating cost of 5.29¢/km. The operating cost whicle running on natural gas alone was 3.90¢/km.

With the gasoline fleet operating at 11.81¢/km, saving for the natural gas group were approximately 6.52¢/km. For the annual travel distance of nearly 242 000 km, actual saving in the first year was $15 773 over and above what gasoline would have cost. This is about a $720 to $750 annual saving in fuel cost for each converted van.

Based on these year-end findings, it was determined that overall gasoline mileage was 0.31 L/km (10 mpg), while the natural gas vans required 0.29 m^3 (10.19 cu ft) to go the same distance. This works out to a fuel equivalence figure of 0.93 m^3 (32.83 cu ft) being equal to 1 L of gasoline, or 4.23 m^3 (149.42 cu ft)/Imperial gallon.

Average gasoline cost during the test period was 38¢/L ($1.73/gallon). In comparison, natural gas equivalent costs were 12.58¢/L (57.22 cents/-gallon).

Finally, approximately 7% of total fuel price, or 0.90¢/L (4.27 cents/-gallon) is attributed directly to the electricity charges for running the compressor.

In short, Table 2 is a concise summary of fleet statistics and results gathered over the duration of the 12-month monitoring program.

4/ FLEET PERFORMANCE

4.1/ Mileage Calculations

Just as gasoline vehicle performance can be assessed by relating volume of fuel used to distance travelled (i.e., litre per kilometre), so too can natural gas performance be analysed in terms of cubic metres (or cubic feet) per kilometre.

Surveying the monthly performance figures for the CNG fleet indicates that the natural gas fuel consumption record was remarkably consistent and exhibited some very definite trends (Table 3).

For instance, cubic metres per kilometre figures over the six months encompassing October 1981 through March 1982 averaged 0.30, with the high of 0.33 in January 1982, and a low of 0.28 in October 1981. Throughout this same period, the gasoline fleet averaged 0.34 L/km, with the high of 0.43 in February 1982 and a low of 0.20 in December 1981.

Correlating these figures from the first six months gives average fuel equivalence of 0.89 m^3 of natural gas/L of gasoline, or 143 cu ft/gal.

In April and May 1982, the approach of warmer weather brought with it a documented mileage improvement in both the CNG and gasoline fleets. Average consumption in the natural gas group decreased to 0.24 m^3/km, a 19% improvement, whereas mileage in the gasoline group dropped to 0.30 L/km representing a 12% improvement.

Correlation of results indicates fuel equivalence of 0.81 m^3 of natural gas/L of gasoline, or 130 cu ft/gallon.

Then, in June, July, August and September, the CNG fleet showed surprisingly consistent mileage figures of 0.22 m^3/km for each of the four months (7.92, 7.77, 7.92 and 7.95 cu ft/km specifically). This "summer" average of 0.22 m^3/km represents a 27% improvement over the "winter" average. Likewise, gasoline mileage improved during the summer months, showing litres per kilometre figures of 0.22, 0.29, 0.24 and 0.28 for

June, July, August and September. The average improvement over the winter mileage of 0.34 L/km was 24%.

Hence, final fuel equivalence statistics for the four summer months were 1.00, 0.76, 0.92, and 0.78 m^3/L, or roughly 138 cu ft/gallon equivalent.

This trend towards improved mileage can be attributed to two things.

Firstly, warmer weather is usually conducive to improved performance from most things mechanical. This certainly holds true for gasoline engines and should do likewise for gaseous-fuelled engines although the total effect of temperature on mileage is typically less than 1%/°C change.

Secondly, it was mentioned in Progress Report No.2 that Alternative Fuel Systems, supplier of the conversion kits, provided each van with improved fuel/air mixers which they felt would impart a mileage increase of up to 10%. As noted above, fuel consumption figures were noticeably reduced for June through September during which time the new mixers were in use.

In conclusion, the overall mileage improvement of 24% is most likely a result of more efficient gaseous-fuel carburation along with warmer weather during the summer months.

4.2/ Dynamometer Tests

Two vans, one Ford and one GMC, were sent to MTC for detailed dynamometer testing in April 1982.

Standard experimental procedure was followed to provide vehicle fuel consumption, exhaust emissions, and performance criteria for both gasoline and natural gas. Transport Canada city and highway test cycles were used in each case.

For gasoline testing, the spark timing was set to the manufacturer's specifications, thereby providing baseline characteristics. During natural gas analysis, the vehicles were set back to the specifications considered appropriate for dual-fuel operation.

Full test results are included as Appendix 2, but salient points can be summarized as follows.

Baseline tests with gasoline indicated that fuel consumption for both the Ford and GM vans was comparable at about 17 L/km, but exhaust emissions from the Ford van were higher while performance was significantly lower.

For example, typical HC, CO and NO_x levels for the GM vehicle under "combined urban driving" simulation were, in grams per mile, 1.29, 8.04 and 1.79, respectively. The Ford van registered 1.65, 13.24 and 5.57 g/mi for the same test. During dynamometer acceleration trials, the GMC managed 0 to 96.6 km/h times averaging 14 s, with peak power of 75 kW at 96.6 km/h. Average acceleration time for the Ford was 17.6 s with a peak power output of 64 kW.

The same tests were conducted using natural gas with advanced spark timing (set at 17° BTCD for the GMC and 23° BTCD for the Ford). In the area of energy consumption, it was determined that the GM van realized a 10% improvement over gasoline while the Ford indicated a deterioration of up to 14%. With respect to emissions, the "combined urban driving" cycle resulted in HC, CO and NO_x readings of 1.51, 0.16, and 1.64 g/mi for the GM; 1.97, 45.28, and 2.59 for the Ford.

In short, HC emissions for both vehicles were slightly higher on natural gas. However, CO emissions dropped over 90% for GM van, but increased 60% for the Ford. NO_x readings were reduced for both vehicles, although the Ford realized the most significant improvement by cutting the gasoline level by 50%.

Acceleration performance between the two vehicles was more comparable than with gasoline with 0 to 96.6 km/h times of 24.1 s for the GM and 23.2 s for the Ford. These times represent an acceleration impairment of 42% and 24% respectively. Peak power at 96.6 km/h also dropped while using natural gas, only producing 47.7 kW from the GM and 44.4 kW from the Ford.

The MTC concluded that conversion of two different vehicles using similar conversion hardware resulted in significantly different operating

conditions, and that the increase in CO, better performance, and decreased NO_x from the Ford indicated the carburation system on this vehicle was producing a fuel-rich mixture.

Other conclusions based upon their limited study observation were:

- that vehicles running on natural gas may achieve energy utilization efficiencies comparable to and higher than those achieved from gasoline,
- use of natural gas may result in a strong reduction of CO emissions, and
- vehicles using natural gas may suffer a major performance drop.

4.3/ Problems Encountered

One of the prime objectives of the demonstration was to gain practical hands-on experience with conversion and refuelling hardware, and in so doing become aware of any inherent shortcomings.

One of the first equipment failures pertained to the vehicle-mounted back-flow preventing check valves.

Although said to be designed for the high-flow rates (up to 200 cu ft/min at the quick-fill facility) and extremely low temperatures (-70°C) experienced during vehicle refuelling, these particular check valves simply proved inadequate for this application.

Loosening of O-rings often resulted in failure of the valves to seat properly. In some cases, this prevented drivers from connecting or disconnecting fill hoses. More commonly, the result was total loss of natural gas fuel supply from the vehicle bleed valve.

While alternate check and fill valve assemblies were being investigated, manually operated quarter-turn ball valves were installed as a temporary solution.

Even ball valves were found to be prone to slow leakage during the operation of the vehicle. This would pressurize the vehicle-mounted refuelling coupling such that the mating component could not be connected.

In addition, use of ball valves made for somewhat less than ideal refuelling via the slow-fill technique. Not only was it less convenient for the users, who had to open the hood to physically turn the valve, but the refuelling process itself becomes highly erratic as far as gas flow is concerned.

Unlike check valves, ball valves do not enable a previously filled vehicle to remain at peak pressure when empty vehicles return alongside and connect to the common header.

This design shortcoming was tolerated for several months while a number of the previous check valves, modified by the manufacturer, were subjected to further field tests.

Continuing problems led to complete fleet retrofit of both the refuelling connectors at the end of the drop hoses, as well as the mating receptacle on the front of the vans. The new probes fully comply with CGA Standard 12.3 specifications, while the receptacles were selected by virtue of a favourable performance record in New Zealand as well as their local availability.

Unfortunately, the onset of cold weather in fall and winter of 1982/83 has been accompanied by a recurrence of check valve failures reminiscent of those experienced precisely one year earlier.

Inspection of problem valves has frequently shown that very minute particles of scale, rust or brass filings have become lodged on the edge of the O-ring or seat. Removing these particles usually corrects the problem.

Other times, no cause whatsoever can be found for a reported leak and pressure testing shows all to be well.

Because these lab tests are conducted indoors at room temperatures, the possibility of hydrate formation at low temperature can be neither verified nor denied and remains a very real possibility. This phenomenon would explain why the problem arises only in winter, and why it has not been documented during indoor tests, nor in New Zealand for that matter.

Of course, should icing or hydrate formation prove to be the main cause of check valve failures, corrective measures would necessitate retrofit of moisture separation equipment, preferably at the inlet to the compressor. In retrospect, this could explain why other fleet operators testing natural gas in similarly cold climates have not experienced the same difficulties. Most of them have incorporated either dessicant filters or methanol injection somewhere in their refuelling station design.

Apart from the fuel cost saving associated with CNG use, perhaps the next most commonly promoted advantage of using a gaseous fuel has to do with the potential for extended oil drain intervals and longer spark plug life.

It was felt that normal spark plug longevity was adequate even for a gasoline-fuelled vehicle, and that regular plug changes are not a prohibitively expensive proposition.

The possibility of extended oil life, on the other hand, could result in fairly significant saving especially under urban driving conditions where vehicles are subjected to a good deal of curbside idling. For this reason, a special oil monitoring program was instituted with the help of Kendall Oil Limited.

Over the duration of the project, three sets of oil samples were drawn from the test fleet and subjected to spectrographic analysis. A cross-section of gasoline-powered control vans were similarly sampled whenever possible, usually at or around 2000 km.

Apart from high copper levels, which Kendall traced to a special additive incorporated at their Pennsylvania refinery as a standard product component, the only recurring contaminant present in prohibitive concentrations was silica.

Usually the result of dust or road dirt getting past air cleaner and breather assemblies, silica has consistently held the recommended oil change intervals to 2000 km or less in those vans so affected.

All 22 natural gas vans and several gasoline units were sampled at least once, although four vehicles in particular were analysed three times throughout the year. A most surprising observation first thought to be coincidence has now been confirmed -- each and every vehicle exhibiting silica contamination was a GM product, while the only consistently silica-free samples were consistently taken from Ford units.

Kendall's opinion on the matter was that GM simply do not know how to design a proper air intake. Checking with GM's research division revealed that Kendall's contension was basically correct -- the most likely source of silica was indeed via their breather apparatus. GM pointed out that these engines do contain a number of aluminum parts namely; pistons, rocker arms, and roller bearings which are approximately 12% silica. Normal wear of these components would contribute silica but not to the extent indicated in the analyses.

Silica contamination in the GM vans limits oil change intervals to the same as those for gasoline-powered vans, typically 2000 to 3000 km. There can be no cost advantage attributed to longer oil life with these vehicles since the source of silica cannot be corrected. Conversely, the Ford vans have been receiving slightly extended drain interval recommendations from Kendall, usually in the area of 4000 to 4500 km.

In short, the recommended oil change intervals for the GM's remain unchanged, while oil in the Ford vans is now being used twice as long.

Oil monitoring will continue in order to determine just how far oil life can be realistically extended, but the general consensus of auto makers and oil refiners is that drain events for gaseous-fuelled vehicles should remain the same as for their gasoline-powered counterparts. In fact, engine problems traceable to oil degradation for those users who insist on extending oil changes beyond the manufacturers recommendations will void their warranties, regardless of type of fuel used.

Other problems encountered over the demonstration period were in reality more like minor annoyances but were indeed unique to the natural gas vans alone.

For instance, drivers found that vehicle performance after conversion required some adjustments on their part, particularly in the early weeks when the major complaint was lack of power.

Acceleration and dynamometer tests conducted during the program verified the fact that typical after-market conversion definitely results in reduced horsepower. Stock gasoline vans, with their representative complement of pipe, fittings, meters and tools, would easily manage 0 to 100 km/h in 22 to 24 s. The identical vehicle running on natural gas over the same road and under the same climatic conditions would usually require 29 to 31 s to achieve the same speed -- a 20% impairment.

Similarly, dynamometer tests show a drop in road horsepower of 30% for the Fords (64 RHP drops to 44 on CNG), and 36% for the GM's (75 RHP drops to 48).

It should be pointed out that none of these vehicles were equipped with a spark advance module, use of which could be expected to help improve the CNG disadvantage noted above.

Several drivers felt that vehicle handling was affected to some extent, blaming the effect on the weight of the high-pressure cylinders. This is understandable considering that the two steel cylinders account for about 180 kg being added alongside the tool bins on the drivers' side of the van. Consequently, negotiation of right-hand turns is, on occasion, accompanied by a perceived shift in the vehicles' centre of gravity, as it leans somewhat away from the direction of the turn. A horizontal cylinder attitude would overcome this effect in vehicles where such an installation could be accommodated.

Along with the check valve failure discussed earlier, the arrival of cold weather had an adverse effect on vehicle startability. Thirteen units occasionally had to start on gasoline and switch over to natural gas. Some units had to start this way once or twice only during the whole year, and usually only on the coldest days. However, two or three other vans had to start on gasoline quite often, while one in particular used this technique virtually every day throughout January and February 1982.

Ease of cold-weather starting has always been listed as a benefit of CNG and the above experiences were somewhat perplexing. Gasoline and propane must be vaporized during carburation, the difficulty of which is increased as temperature drops. Natural gas, however, is always in the gaseous state and should therefore mix with air and ignite much more rapidly regardless of temperature.

Although reasons for the hard-starting situations noted above were never positively identified, moisture and possibly hydrate icing are believed to be the most likely causes. Again, methanol injection or molecular sieve moisture removal would, in all likelihood, solve the problem.

Minor problems were reported with faulty dashboard-mounted pressure gauges, and a most curious whistling noise which occasionally emanated from around the cylinder shutoff valves. Drivers stated that at times this noise was so annoying that they were forced to switch over to gasoline. The former was quickly attended to by the manufacturer, while the latter proved to be so intermittent, infrequent and elusive as to prevent detailed investigation.

Finally, each and every cylinder shutoff valve had the protective over-pressure burst discs changed once the CGA Standard was finalized.

Available in two configuration, these discs offer cylinder protection by dumping gas under one of two conditions -- either under excessive pressure alone, or, due to excessive pressure in conjunction with high temperatures. The first is accomplished by rupture of a special metal foil, while the second condition requires that a temperature-sensitive fusible alloy first be melted out before the foil backing can rupture.

Rather than rely on the presence of a fire to exceed the burst rating, all vans were initially equipped with the pressure-only relief discs. However, it was found that repeated fill and empty cycles stressed the foil to the point where slow leaks were developing with the risk of fatigue failure. This finding, along with the eventual CGA requirement that a fusible burst disc be used, resulted in the aforementioned change-over such that all vehicles are now protected to 212°F and 5000 psig rather than just 4000 psig alone.

5/ COMPRESSOR AND REFUELLING STATION PERFORMANCE

As part of the monitoring program, pertinent data regarding compressor operation was recorded. Daily readings of hours of operation, electric consumption and total gas throughput were logged and reduced to monthly statistics.

Table 3 is a month-by-month summary of overall compressor operation, detailing the above parameters as well as associated energy costs.

Through the 12 months encompassing October 1981-September 1982, the Norwalk compressor processed almost 68 000 m^3 (2400 Mcf) of natural gas costing $8536.68. This required 11 094 kWh of electricity at $688.95, with a running time of 577 h. The total CNG fuel cost was $9225.63.

As mentioned above, these figures are the overall results, and although most of the gas went to fuel the vans directly, a good deal was dispensed to other operators of CNG vehicles.

Throughout its first year of operation, the Eastern Avenue location was in fact the only source of high-pressure vehicle gas in Ontario. As a result, a somewhat heavier-than-normal demand was placed on the station as other fleet managers insisted on trying a few test vehicles, but were hesitant to install their own refuelling stations.

In addition to these occasional users, four gas company construction and maintenance trucks were converted during spring and summer 1982, each of which was comparable to adding two service vans as far as gas capacity is concerned. And the MTC contracted Consumers' Gas to convert a Ford pickup truck using the same conversion hardware as was used on the vans, enabling them to conduct their own detailed evaluations.

Extraneous fillups were carefully logged for two reasons -- for billing purposes, and to keep track of gas volumes which passed through the master gas meter without even being used by Consumers' vans.

In short, 7365 m^3 (160 Mcf) of compressed gas was distributed to vehicles other than the 22 van test fleet, but this practice stopped with the opening of the first public CNG facility in late December 1982.

The most noticeable trend from Table 3 is towards reduced compressor operating time, and hence, lower gas and electric loads as warmer weather approached.

Throughout the monitoring period, distance travelled by the test vans remained relatively constant, therefore decreased gas consumption can be mainly attributed to a reduction in vehicle idle time. That is, during summer months the drivers have no need to keep the cab warm while making service calls, so they readily shut off the engine. The same trend was observable in the gasoline control group.

Over the duration of the demonstration, 249 sets of readings were taken at the compressor station, one set per day. Therefore, it is estimated that the 25-horsepower motor operated, on average, only 2.3 h/day. At a throughput of 100 m^3/h (65 scfm), roughly 255 m^3 (9000 cu ft) went into the 22 vans each night, the total cost of which was approximately $33. In other words, each van required an average of 11.6 m^3 (409 cu ft) of gas per shift, which is precisely the capacity of one storage cylinder.

From the above, one may be tempted to conclude that one cylinder would have provided sufficient daily range. However, it should be stressed that these figures are based on year-end results, averaged over 22 vehicles. In reality, actual differences between operating shifts and individual vans are remarkable, and even the combined capacity of two cylinders would often be required to complete a normal shift.

Nevertheless, the fact remains that there is at least a further eight hours of surplus slow-fill time available each night. It is expected that the addition of the 12 unit construction and maintenance fleet will easily double the gas throughput and fill times required.

Finally, it should be noted that the only regular maintenance carried out over the project duration was topping up of compressor lube oil. Five gallons were used costing about $100.

5.1/ Problems Encountered

Over a three- or four-week break-in period, premature compressor shutdown occurred several times. The problem was corrected by recalibrating an oil level switch, and by adding a small gravity-fed auxiliary lubricating oil reservoir directly above the crankcase. In addition, a master check valve on the compressor outlet failed in the eighteenth month after 850 h of operation. The system was down for five days while awaiting delivery of the replacement.

Other problems were unique to the refuelling operations. Mainly because of the significant variability in gas quality throughout much of the United States, many utilities have found it necessary to install expensive moisture and oil removal facilities on their CNG stations.

However, because Western Canadian gas is remarkably consistent with regards to energy content and relatively low moisture levels, it was decided that special treatment equipment would only be added if and when required.

In the third month of operation, it became apparent that a small amount of compressor lubricating oil was by-passing the crankshaft and pistons, eventually ending up in the high-pressure gas steam. The problem was first identified during vehicle maintenance when mechanics noticed oil accumulation in the bottom of the CNG regulators.

Although the presence of oil in the gas has never been identified as the source of any particular problem, it was decided that removing the oil would reduce the likelihood of later difficulties. An oil separator was installed on the compressor outlet, and weekly draindown of the accumulator provides about 0.25 L of lube oil.

Early in the program, a number of the flexible drop hoses developed very minor leaks due to gas permeation through the wrappings. It is for this reason that the outer material of many gas transfer hoses must consist of a special pin-prick covering, and these hoses were no exception.

All 25 were replaced with an improved type, but again the problem reappeared eight months later. In fact, the first gas leak indications are small oil stains surrounding the leak site. In cool weather, a much more dramatic indication is a complete frosting of the hose, usually accompanied by numerous small blisters and bulges in the outer casing.

For the third time, all hoses have been replaced with another type, but only time will tell if the problem persists.

Early in the program, each and every fill valve assembly was replaced with a more compact, reliable and safer type. The initial arrangement consisted of two quarter-turn ball valves at the end of the flexible hose, one of which allowed gas flow to the vehicle tanks, while the other provided for pressure relief prior to disconnecting the hose. Slow leaks and increasingly frequent driver complaints resulted in selection of a three-way valve specifically designed for natural gas use.

Looking much like a cylinder shutoff valve, this particular device, the three-way valve, combines both the fill and bleed functions into one convenient operation. Apart from the occasional handle breaking off due to excessive tightening, performance of these valves has been adequate.

Problems were experienced in late March 1982 with the automatic cascading operation of the quick-fill facility.

The system is designed for sequential depressurization wherein three isolated banks of cylinders are meant to be automatically drawn upon one after the other. When pressure in the first bank decreases to the point where reservoir pressure equalizes with vehicle pressure, the first bank is isolated and the quickfill is completed by "topping up" with the second bank. The process continues to the third bank, if required, and back to the first bank which has since been recharged by the compressor.

However, for some unknown reason, the sequential control valves would occasionally seize in the open position such that all three banks would depressurize at the same time. Although high-pressure gas would still be dispensed and quickfilling could still be accomplished in less than five minutes, the fact remains that something was preventing these components from operating as they should.

The intermittent nature of the problem continually hampered diagnostic investigations, and it was finally decided to replace all O-rings and seals within the sequential valves.

This appears to have corrected the problem, but it should be stressed that servicing of automatic cascade controls is difficult and time-consuming. The relative simplicity of manually-controlled cascading systems means they tend to be superior with respect to serviceability and reliability, and would be highly recommended for other fleet operators who desire the versatility of a quick-fill station. On the other hand, fully automatic cascading systems are an absolute necessity for public CNG outlets, and significant design improvements have already been made to cascade packages offered by other promoters.

For the most part, the refuelling station has operated as planned, requiring very little in the way of maintenance. The recent retrofit of a dome-loaded regulator from Dual Fuels Inc. has somewhat improved the operation since the cascade storage now operates at 24.8 MPa (3600 psig) while the regulator only allows the slow-fill header to provide the temperature-compensated equivalent of 20.7 MPa (3000 psig) at 21°C.

The only other possible revision which would be implemented if hydrate problems are verified is the installation of moisture removal equipment.

6/ PROMOTION

Now that a full year of operating data and performance results are available, an intensive information transfer scheme based on these findings can be brought into effect.

Even so, several promotional opportunities were taken advantage of throughout the course of the demonstration period long before any final results were produced.

Research department personnel attended a number of speaking engagements and presented the details of the project to several professional groups including the Metro Toronto Public Utilities Coordinating Committee, the Ontario School Bus Operators Association, the National Association of Fleet Administrators, the American Public Works Association, and the Ontario Natural Gas Association/Canadian Gas Association Operating Workshop.

Whenever possible, one of the CNG-powered vans was brought along and put on display for the benefit of delegates interested in seeing a working conversion.

More recently, Consumers' marketing department has taken an active role in natural gas vehicle promotion by preparing a portable exhibit designed for trade show participation. The exhibit includes a converted fleet vehicle surrounded by posters showing refuelling station schematics, a display of conversion hardware, a professionally-produced audio visual slide presentation, and informative handout pamphlets.

Variations of this display were used at the Truckcan Show held in November 1981, and at the Toronto International Auto Show held in February 1982.

Promotions of this sort have resulted in fleet operators requesting more detailed information, and many have already been given tours of the refuelling station. Interested operators have included the Toronto Star and Globe and Mail newspapers, Oshawa City Council, the City of North York, Borough of Etobicoke, Canada Post, Air Canada, Ontario Paper, and Canadian National Railways.

As previously mentioned, Consumers' quick-fill facility was the only source of high-pressure natural gas in Ontario during the 12-month demonstration. As a result, a somewhat heavier-than-anticipated demand was placed on the station, but this was accepted as one of the promotional benefits of the program.

Throughout the summer of 1982, most of the extraneous fillups were billed to CNG Fuel Systems Ltd. Approximately ten of their own company cars and two or three demonstrator vans required frequent refuelling, while a number of customer conversions were filled on a one-time-only basis to enable proper engine tuning. These customers included Purolator Courier, Globe and Mail newspapers, Simpsons, Palace Pier Condominiums, Outboard Marine Corporation, Centennial College, and Union Gas Company, the latter having since completed the installation of their own compressor plant in Hamilton.

Other occasional users were Emgas Systems and FIBA-Canning, both of which market natural gas-vehicle hardware in the Toronto area. Repeat fillups were also granted to a test Ford pickup truck operated by the MTC.

Forthcoming schemes aimed at increasing awareness amongst the general public include media coverage, gas bill inserts and possibly static, unmanned shopping mall displays.

Recognizing that fleet operators are still the ones most likely to benefit from CNG utilization in the near term, a number of promotional seminars specially tailored for this target group are being considered. Highlighted by a slide show and detailed economic feasibility case studies, these seminars may also include a tour of the Eastern Avenue station.

These informative programs were carried out by mid-summer 1983.

7/ ECONOMICS

At the onset of the demonstration program, economic feasibility calculations indicated that a 28-vehicle fleet utilizing slowfill alone would result in an annual per-vehicle fuel saving of $797.79 over what gasoline would have cost.

In reality, per-vehicle saving in the first year was very close to the predicted saving at $720 to $750 although total project implementation costs (compressor station, conversions, and labour) were significantly higher than anticipated.

Because this was the very first high-pressure natural gas vehicle fill station being built in Ontario, safety became one of the highest priority items during preparation of detailed plans and drawings. For this reason, the station may be considered somewhat overdesigned in some respects, but minimizing the possibility of an incident at this early stage was a very important consideration.

Secondly, it was decided that demonstration of state-of-the-art technology should take precedence over project financial feasibility. For instance, the compressor package envisaged at the outset was to have been specifically sized for a 28-vehicle fleet. It was later decided that a much larger compressor capable of handling 40 to 50 vehicles should be used to accommodate fleet expansion.

In addition, a quick-fill facility, although never required for Consumers' fleet specifically, was added nonetheless when it became obvious that many other vehicle users would appreciate the opportunity of trying CNG without having to install their own compressors.

These substantial changes resulted in a much more reliable and flexible refuelling station design, but at a higher installation cost. Attempting to recover the cost of a large capacity facility from the saving generated by a relatively small fleet would be a futile exercise. However, this situation is expected to improve when most of the remaining vehicles working out of this location are converted.

The bulk of these additional vehicles are large trucks used for pipeline construction and maintenance, an application characterized by low daily mileage but very high fuel consumption. Typically, each truck is stationed at a work site through the day, with the engine running constantly in order to power the various tools.

One such truck was converted on a test basis midway through the demonstration program (Figure 7). Fuel history records indicated that this particular unit formerly used up to 36 L of gasoline/day which, at 38¢/L, would cost nearly $14. With sufficient daily on-board capacity of 45 m^3 (1600 cu ft) of natural gas, this truck consistently saved at least $9/shift over and above what gasoline would have cost. Since it is used about 260 days/yr, this one vehicle can easily recover the $2300 conversion cost in just over 12 months.

Eight of these units are now running on natural gas, with four more scheduled for conversion. Each one of these trucks is comparable to adding two vans as far as increased gas load is concerned, but the saving realized are far better. In view of the gasoline volumes displaced, these 12 units could each save up to $2000/yr for a total annual saving of around $24 000.

This, in conjunction with the 22 vans, represents combined fleet saving of nearly $40 000/yr.

The additional costs to convert 12 trucks and expand the refuelling line leaves the total expenditure to be recovered at $180 000. In light of the fuel saving achieved in year one, and the fact that the station is now operating near its design capacity, it is estimated that all invested capital will be recovered within the next five years. However, it is recognized that the years-to-payback technique is rather simplified and, to some extent an unrealistic economic treatise.

Consumers' Economic Studies group used several detailed approaches to examine the feasibility of a number of refuelling station designs, capacities and scenarios, and eventually selected the discounted cash flow/net present value methodology. Using this methodology, the effects of income taxes, depreciation, incentive programs and annual escalation of

few saving can be used to full advantage. Furthermore, by discounting the net fuel saving (cash inflows) against the initial capital expenditure (cash outflows) over the economic life of the project, the present value of the future net cash flows to the project can be determined.

Table 4 represents the feasibility printout for the Consumers' Gas demonstration using this approach. The bulk of the computer treatment is not shown, but it should be mentioned that a number of assumptions have been made. For instance, the total plant investment of $190 500 takes into account the capital cost of refuelling station hardware and vehicle conversion equipment for the 34-vehicle fleet (as opposed to the 22 vans alone), and includes all associated labour charges. In addition, federal and provincial conversion grants and tax incentives have been deducted from several of the recently-converted C & M trucks.

Cash inflow was taken as the difference between the cost of gasoline and the cost of compressed natural gas as deduced from the first year operating history. Gasoline and natural gas costs were assumed to escalate in subsequent years based on price estimates derived by Canadian Resourcecon in their October 1982 study. The major cash outflow is, of course, the substantial capital investment made in year one, along with annual service and maintenance cost estimates.

The tax shield from depreciation (i.e., the amount by which the company tax liability is reduced by depreciation) was also incorporated into the analysis. A 20% capital cost allowance (C.C.A.) on refuelling station hardware was utilized along with the 30% C.C.A. on vehicle conversion equipment.

The net cash flows were discounted using an after-tax cost of capital of 10.02%. The cost of capital considers the debt/equity proportion of the firm's capital structure weighted by the debt cost and expected equity return from each source of capital.

All things considered, the major areas of interest have been highlighted with asterisks on Table 4. First, the table includes a simple payback calculation indicating full capital recovery between the fifth and sixth year (item 95C). However, the much more intensive series of calculations

utilizing the assumptions noted above result in net present value and benefit/cost ratios as indicated (items 55 C and 58 C). Based on this information, it is deduced that the overall project will become profitable in, or shortly after, the eighth year of operation.

8/ OTHER DEVELOPMENTS

It was recognized very early in the program that the idea of providing compressed natural gas to private motorists would require a suitable metering and billing device analogous to current gasoline pumps.

One of the first CNG dispensing meters developed for this purpose was brought on the market in the fall of 1981. Manufactured by Euromatic Machine and Oil (Channel Islands, U.K.), a prototype package was secured for test purposes from the North American distributor, FIBA-Canning Limited.

The flowmeter, pressure, and temperature-sensing instrument was installed on the quick-fill facility with the computer and display located on an outside wall near the compressor shed (Figure 8). This was followed by several months of tedious troubleshooting.

When it became obvious that accuracy would only approach 4%, FIBA-Canning arranged to have an engineer from Euromatic attend to the matter.

A number of detailed modifications were made to the unit including re-programming, rewiring, and replacement of several electronic components. Accuracy was checked using a precision weigh scale and a small, light-weight natural gas storage cylinder. Comparing weighed gas volumes to those shown on the display indicated an accuracy of 10% -- the best that could be accomplished using the beam scale.

In December 1982, both federal and provincial officials from Weights and Measures carried out detailed tests of their own using a similar volume-by-weight approach. These investigations culminated in detected accuracies of ±1%.

Reflecting both the Company commitment to natural gas vehicles and the fact that earlier vehicle conversions have proved economically feasible, plans are now under way to construct two more refuelling stations on the outskirts of Toronto.

Located at service depots in Scarborough and Mississauga, these additional facilities, along with the Eastern Avenue location, will result in a refuelling network strategically covering Consumers' Metro area.

The two new compressors have been ordered, neither of which is the same as the Norwalk NQSV2 already in use. One is an Idro Meccanica unit, while the other is a Norwalk three-stage model. Different machines were specified for two reasons -- to provide hands-on experience with various hardware, and for research purposes.

Approximately 40 vehicles will be converted at each new station, for a total anticipated natural gas-powered fleet numbering 114 units.

In other areas, several developments are worthy of mention.

The introduction of compressed natural gas into the public sector was initially faced with a "chicken-and-egg" dilemma with regards to vehicle conversion centres and public refuelling facilities. Since the onset of the demonstration program, several organizations have established themselves in the after-market vehicle conversion business within Consumers' area. Very good working relationships continue with these firms, including CNG Fuel Systems Limited, EMGAS Systems and FIBA-Canning.

In late December 1982, the first public refuelling station became operational in southwest Toronto. This is a joint venture between Shell Canada Limited and CNG Fuel Systems Limited, and the response to this precedent-setting development will be observed with keen interest.

In addition to their conversion and training centre, CNG Fuel Systems have also constructed a large compressor manufacturing plant in Brampton.

In no way can Consumers' demonstration program claim responsibility for these rather significant developments. Rather, they are pointed out merely to recall one of the contentions highlighted in the original program proposal concerning creation of new employment opportunities. Should the present trend continue, a completely new, indigenous industry is entirely conceivable.

9/ CONCLUSIONS

Monitoring of the test fleet against the control group of gasoline vans has proved to be of immense value with regard to the performance and cost comparison data produced. Armed with these results, an effective information transfer scheme will be brought into effect aimed at increasing awareness of the CNG option in both public and commercial sectors.

Through carefully monitored dynamometer tests, it has been shown that natural gas emissions are indeed reduced over those from gasoline-fuelled engines, but generally with a noticeable performance drop.

Oil analyses indicate that the ability to extend oil change intervals is highly dependent upon the manufacturer, and that doubling of useful service life can be realized in some instances.

Problems and solutions experienced with the natural gas fleet and compressor plant served as a proving ground for the ongoing development of natural gas-related standards and regulations. It is felt that experience thus gathered has proved beneficial in ensuring the safe and orderly progression of these standards.

The project has given, and will continue to give, other fleet operators the opportunity of seeing firsthand a working, commercial fleet utilizing natural gas in day-to-day activities.

Finally, it has been demonstrated that natural gas is indeed a viable automotive fuel, although proper station sizing and design capacity are critical variables with regards to economic feasibility of such a project.

APPENDIX A/ FLEET VEHICLE IDENTIFICATION

UNIT NUMBER	YEAR	MFG. NAME	UNIT NUMBER	YEAR	MFG. NAME
11-299	1981	FORD VAN	12-331	1982	FORD VAN
11-300	1981	FORD VAN	12-347	1982	FORD VAN
11-302	1981	FORD VAN	12-373	1982	FORD VAN
11-303	1981	FORD VAN	12-378	1982	FORD VAN
11-311	1981	FORD VAN	17-395	1977	GMC VAN
11-644	1981	GMC VAN	12-426	1982	FORD VAN
11-652	1981	GMC VAN	12-455	1982	FORD VAN
11-653	1981	GMC VAN	12-489	1982	FORD VAN
11-659	1981	GMC VAN	17-529	1977	DODGE VAN
11-675	1981	GMC VAN	17-582	1977	DODGE VAN
11-676	1981	GMC VAN	15-609	1975	GMC VAN
11-693	1981	GMC VAN	19-747	1979	FORD VAN
11-699	1981	GMC VAN	10-794	1980	FORD VAN
11-711	1981	GMC VAN	12-820	1982	FORD VAN
10-717	1980	FORD VAN	15-838	1975	FORD VAN
11-729	1981	GMC VAN	16-917	1976	GMC VAN
10-732	1980	FORD VAN	16-922	1976	GMC VAN
11-741	1981	GMC VAN	16-928	1976	GMC VAN
11-743	1981	GMC VAN	11-960	1981	DODGE VAN
11-757	1981	GMC VAN			
10-799	1980	FORD VAN			
10-905	1980	GMC VAN			

APPENDIX B/ MTC DYNAMOMETER TEST RESULTS

Vehicle Specifications		
Type	Van	Van
Make	GMC	Ford
Model	Vandura 25	E-150
Model Year	1980	1980
Licence No.	AE8-857	AF6-523
Kilometrage	38789 to 40123	25239 to 26435
Gross Vehicle Weight	3000 kg	2815 kg
Engine Type	Gasoline; L-6	Gasoline; L-6
Engine Size	4.1 L	4.9 L
Transmission Type	A-3	A-3
Carburetor Type	2-BBL	2-BBL
Oxidation Catalyst	Yes	Yes
Air Injection	No	No
Exhaust Gas Recirc.	Yes	Yes
Evaporation Canister	Yes	Yes
Positive Crankcase Vent.	Yes	Yes

APPENDIX B/ MTC Dynamometer Test Results (Cont'd.)

Dynamometer Parameters		
	GMC Vandura 25	Ford E-150
Inertia Weight	2041 kg	2041 kg
Indicated Road Load*	13.5 hp	14.8 hp
Actual Road Load*	16.5 hp	17.5 hp
Tire Pressure	310 kPa	310 kPa
Cell Temperature	25°C	25°C
Cell Humidity	23.9 gr/lb	20.5 gr/lb
Cell Pressure	100 kPa	100 kPa

*At 96.6 km/h (60 mi/h)

APPENDIX B/ MTC Dynamometer Test Results (cont'd.)

Vehicle Diagnostics

With Natural Gas

		GMC Vandura 25	Ford E-150
Curb Idle	(RPM)	740	680
Basic Timing at Idle	(°BTDC)	17	23
Total Timing at 2500 RPM	(°BTDC)	53	54
Idle HC Emissions	(ppm)	0	0
Idle CO Emissions	(%)	0.15	1.0

With Gasoline

Curb Idle	(RPM)	750(650)**	820(700)**
Basic Timing at Idle	(°BTDC)	10(10)**	10(10)**
Total Timing at 2500 RPM	(°BTDC)	31	40
Idle HC Emissions	(ppm)	20	30
Idle CO Emissions	(%)	0.01	0.08

*Data in this table were obtained with garage equipment and should be considered qualitative only.

**Manufacturers' specifications

APPENDIX B/ MTC Dynamometer Test Results (Cont'd.)

Fuel Consumption, Exhaust Emissions and Performance with Gasoline

		GMC Vandura 25	Ford E-150
Fuel Consumption			
Urban Driving			
Cold-transient	(L/100 km)	17.94	18.33
Stabilized	(" ")	17.45	16.99
Hot-Transient	(" ")	15.43	16.55
Combined	(" ")	17.06	17.04
Highway Driving	(" ")	12.50	13.13
Idling (Park)	(L/h)	2.19	2.44
Idling (Drive)	(L/h)	2.11	2.39
48.3 km/h Cruise	(L/100 km)	9.64	9.49
96.6 km/h Cruise	(L/100 km)	14.66	14.68
Hydrocarbon Emissions			
Urban Driving			
Cold-Transient	(g/mi)	2.71	1.90
Stabilized	(")	0.868	1.58
Hot-Transient	(")	1.020	1.61
Combined	(")	1.29	1.65
Highway Driving	(")	0.302	0.72
CO Emissions			
Urban Driving			
Cold-Transient	(g/mi)	17.81	34.25
Stabilized	(")	4.53	5.81
Hot-Transient	(")	7.34	11.44
Combined	(")	8.04	13.24
Highway Driving	(")	3.52	3.81

APPENDIX B/ MTC Dynamometer Test Results (cont'd.)

NO_x Emissions		GMC Vandura 25	Ford E-150
Urban Driving			
Cold-Transient	(g/mi)	2.57	6.83
Stabilized	(")	1.35	4.19
Hot-Transient	(")	2.04	7.21
Combined	(")	1.79	5.57
Highway Driving	(")	1.61	7.68
Performance			
0 to 96.6 km/h Acceleration Time			
In Drive (s)		14.0	17.6
In Second (s)		14.4	10.0
Power delivered at 96.6 km/h and WOT operation			
In Drive (kW)		75.0	64.0
In Second (kW)		75.0	60.3

APPENDIX B/ MTC Dynamometer Test Results (Cont'd.)

Fuel Consumption, Exhaust Emissions and Performance with Compressed Natural Gas

Fuel Consumption		GMC Vandura	Ford E-150
Urban Driving			
Cold-Transient	(m^3/100 km)	15.20	19.07
Stabilized	(" ")	15.79	17.19
Hot-transient	(" ")	14.49	17.41
Combined	(" ")	15.29	17.66
Highway Driving	(" ")	11.76	14.49
Idling (Park)	(m^3/h)	2.30	2.33
Idling (Drive)	(")	2.19	2.22
48.3 km/h Cruise	(m^3/100 km)	8.46	10.30
96.6 km/h Cruise	(" ")	12.71	16.18
Hydrocarbon Emission			
Urban Driving			
Cold-Transient	(g/mi)	1.83	2.26
Stabilized	(")	1.36	1.91
Hot-Transient	(")	1.55	1.86
Combined	(")	1.51	1.97
Highway Driving	(")	0.77	1.67

APPENDIX B/ MTC Dynamometer Test Results (Cont'd.)

CO Emissions		GMC VANDURA	Ford E-150
Urban Driving			
Cold-Transient	(g/mi)	0.58	68.70
Stabilized	(")	0.03	32.17
Hot-Transient	(")	0.03	52.64
Combined	(")	0.16	45.28
Highway Driving	(")	0.03	46.21
NO_x Emissions			
Urban Driving			
Cold-Transient	(g/mi)	3.02	2.42
Stabilized	(")	0.99	2.44
Hot-Transient	(")	1.85	3.01
Combined	(")	1.64	2.59
Highway Driving	(")	1.48	2.98
Performance			
0 to 96.6 km/h Acceleration Time			
In Drive (s)		24.1	23.2
In Second (s)		23.8	27.3
Power delivered at 96.6 km/h and WOT operation			
In Drive (kW)		47.7	44.4
In Second (kW)		45.6	44.4

APPENDIX B/ MTC Dynamometer Test Results (Cont'd.)

Energy Consumption with Gasoline and Natural Gas (Comparison of Energy Utilization Efficiencies)

GMC Vandura 25

	Gasoline	CNG	CNG Advantage
Urban Driving (MJ/100 km)	553	515	7%
Highway Driving (MJ/100 km)	405	396	2%
Idling (in Drive) (MJ/h)	68	74	-9%
Cruise (48.3 km/h) (MJ/100 km)	313	285	9%
Cruise (96.6 km/h) (MJ/100 km)	475	428	10%

Ford E-150

Urban Driving (MJ/100 km)	552	594	-8%
Highway Driving (MJ/100 km)	426	486	-14%
Idling (in Drive) (MJ/h)	77	75	-3%
Cruise (48.3 km/h) (MJ/100 km)	308	347	-13%
Cruise (96.6 km/h) (MJ/100 km)	476	544	-14%

*Positive numbers indicate an energy utilization efficiency advantage for the CNG system.

Table 1/ Monthly Fleet Fuel Use Summary

	Gasoline Group			CNG Group						
Month	Distance (km)	Litres	Cost ($)	Distance (km)	Gas Use (m^3)	Gas Cost ($)	Electric Use (kWh)	Electric Cost ($)	Operating Hours	Total CNG Cost ($)
October and November 1981	26 920	8 847	3 276.80	41 166	13 087.5	1 478.40	2 138	132.80	94.1	1 611.20
December 1981	21 850	6 400	2 415.66	17 846	5 948.8	672.00	933	57.94	44.0	729.94
January 1982	21 975	6 762	2 546.17	17 830	6 798.7	768.00	1 066	66.20	52.9	834.20
February 1982	16 318	7 075	2 698.12	19 128	6 345.4	828.80	1 030	64.00	51.4	892.80
March 1982	20 077	6 742	2 578.50	20 420	5 920.5	773.30	905	56.24	47.6	829.54
April and May 1982	29 859	9 059	3 518.65	36 590	9 404.8	1 228.40	1 551	96.31	87.0	1 324.71
June 1982	15 868	3 507	1 379.14	15 998	3 795.9	495.80	637	39.58	35.9	535.38
July 1982	16 558	4 936	1 915.52	12 863	2 832.8	370.00	486	30.20	28.3	400.20
August 1982	10 513	2 500	931.92	10 851	2 606.2	365.24	445	27.63	26.4	392.87
September 1982	16 885	5 234	1 988.92	17 224	3 880.9	602.06	672	41.74	39.7	643.80
Totals	196 823	61 062	23 249.40	209 916	60 621.5	7 582.00	9 863	612.64	507.3	8 194.64

Table 2/ Year-end Results

	Gasoline Group	Natural Gas Group
Distance (km)	196 823	209 916 (CNG) + 32 000 (gasoline) = 241 916*
Volume	61 062 L	2 140 000 cu ft + 11 856 L
Cost	$23 249.40	$8194.64 + $4629.05 = $12 823.69
Operating Cost	11.81¢/km	5.29¢/km
Average Mileage	0.31 L/km	10.19 cu ft/km
Savings -	6.52¢/km x 241 916 km = $15 773 (approx. $720 to $750/vehicle/year)	
Fuel	32.87 cu ft = 0.93 m^3 = 1 L gasoline	-- 12.58¢**
Equivalence	149.42 cu ft = 4.23 m^3 = 1 Imp Gal gasoline	-- 57.22¢**

*85% natural gas utilization.

**Electricity charge makes up 4.27¢/gal equiv. (0.94¢/L equiv.)

Table 3/ Compressor Operation -- Station B October 1981-September 1982 Inclusive

Month	Metered Gas Throughput (Mcf)	Gas Cost ($)	Electric Consumption (kWh)	Electric Cost 6.21¢/kWh ($)	Hours of Operation	Total CNG Cost ($)
October 1981	250	800.00	1 155	71.76	50.4	871.76
November 1981	212	678.40	983	61.04	43.7	739.44
December 1981	210	672.00	933	57.94	44.0	729.94
January 1982	240	768.00	1 066	66.20	52.9	834.20
February 1982	248	917.60	1 141	70.86	56.9	988.46
March 1982	243	899.10	1 053	65.39	55.4	964.49
April 1982	215	795.50	992	61.60	55.7	857.10
May 1982	172	636.40	817	50.74	45.9	687.14
June 1982	161	595.70	766	47.56	43.2	643.26
July 1982	117	432.90	569	35.33	33.2	468.23
August 1982	140	555.80	677	42.04	40.2	597.84
September 1982	192	785.28	942	58.49	55.6	843.77
Totals	2 400 000	$8 536.68	11 094 kWh	$688.95	577.1	$9 225.63
Used by Vans Alone	2 140 000	$7 582.00	9 863	$612.64	507.3	$8 194.64

Table 67 Consumers' Gas DSI Demonstration — Net Present Value Economic Feasibility Study

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]

Cylinder Installation
Details

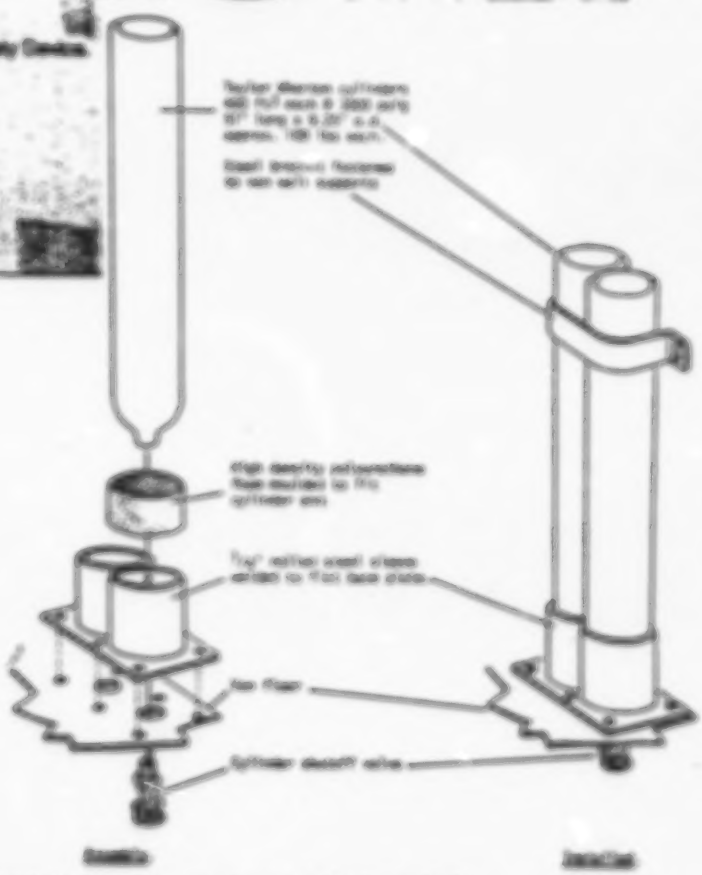


Figure 1/ Typical Service Van Converted for Operating on Natural Gas

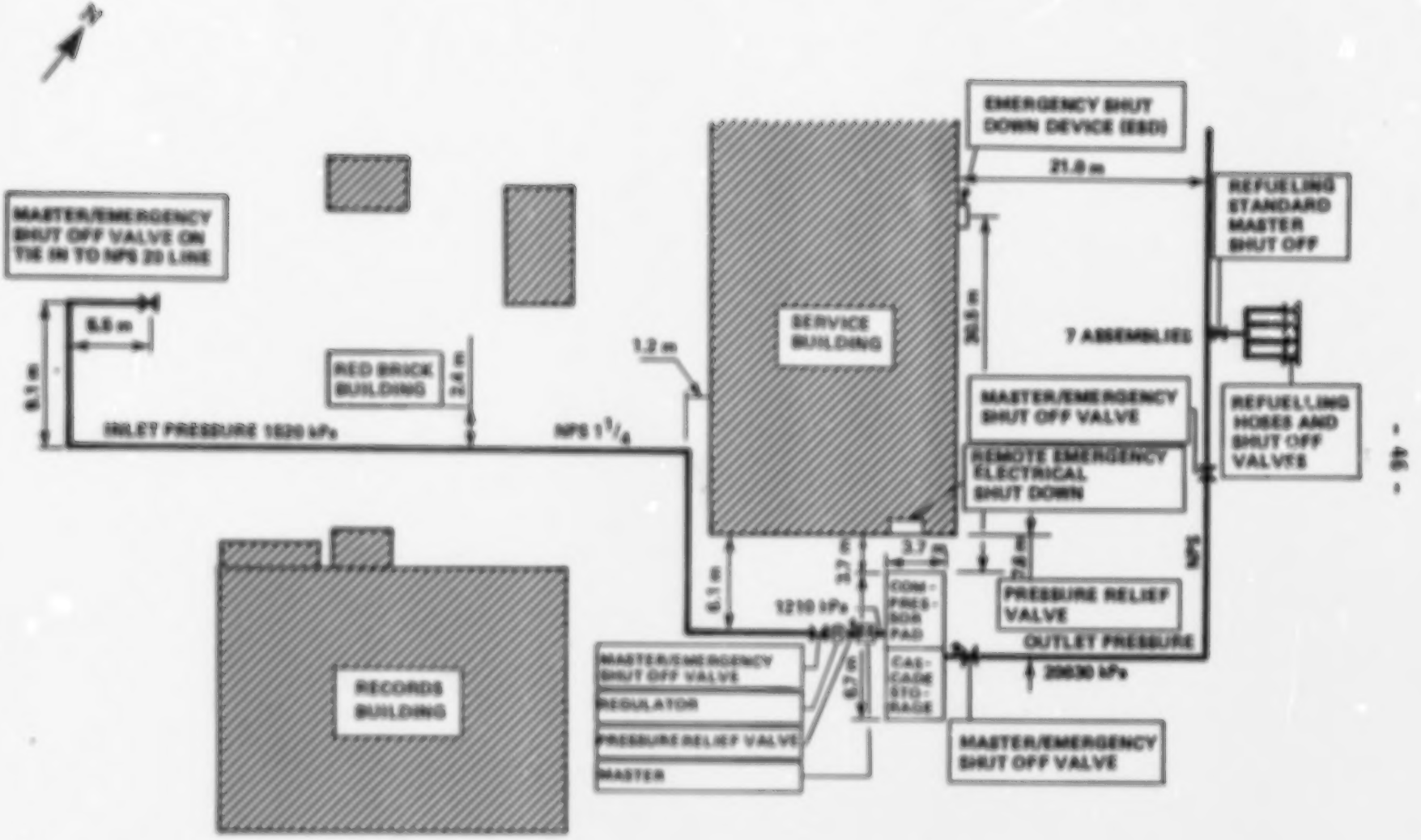


Figure 2/ CNG Refuelling Facility Layout Station 'B' Toronto

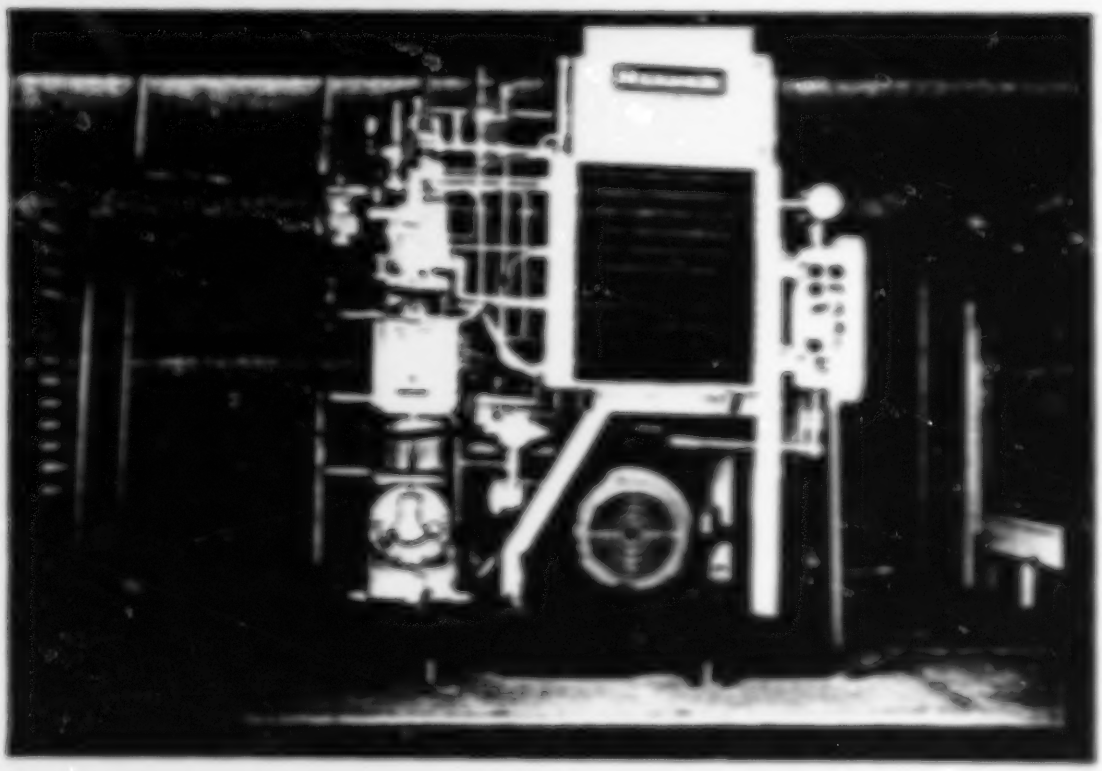


Figure 3/ Norwalk HQ5Y2 Natural Gas Compressor

Figure 4/ Slow-fill Refueling System

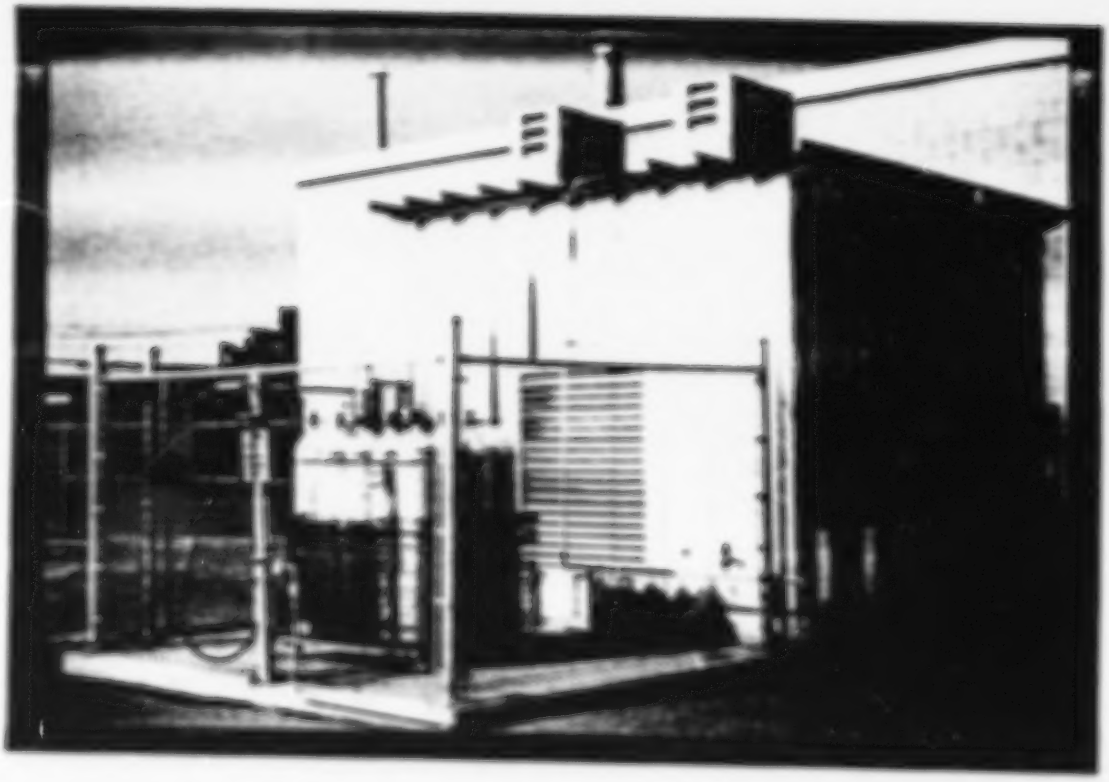


Figure IV Compressor Shed and Quick-fill Cascade Facility

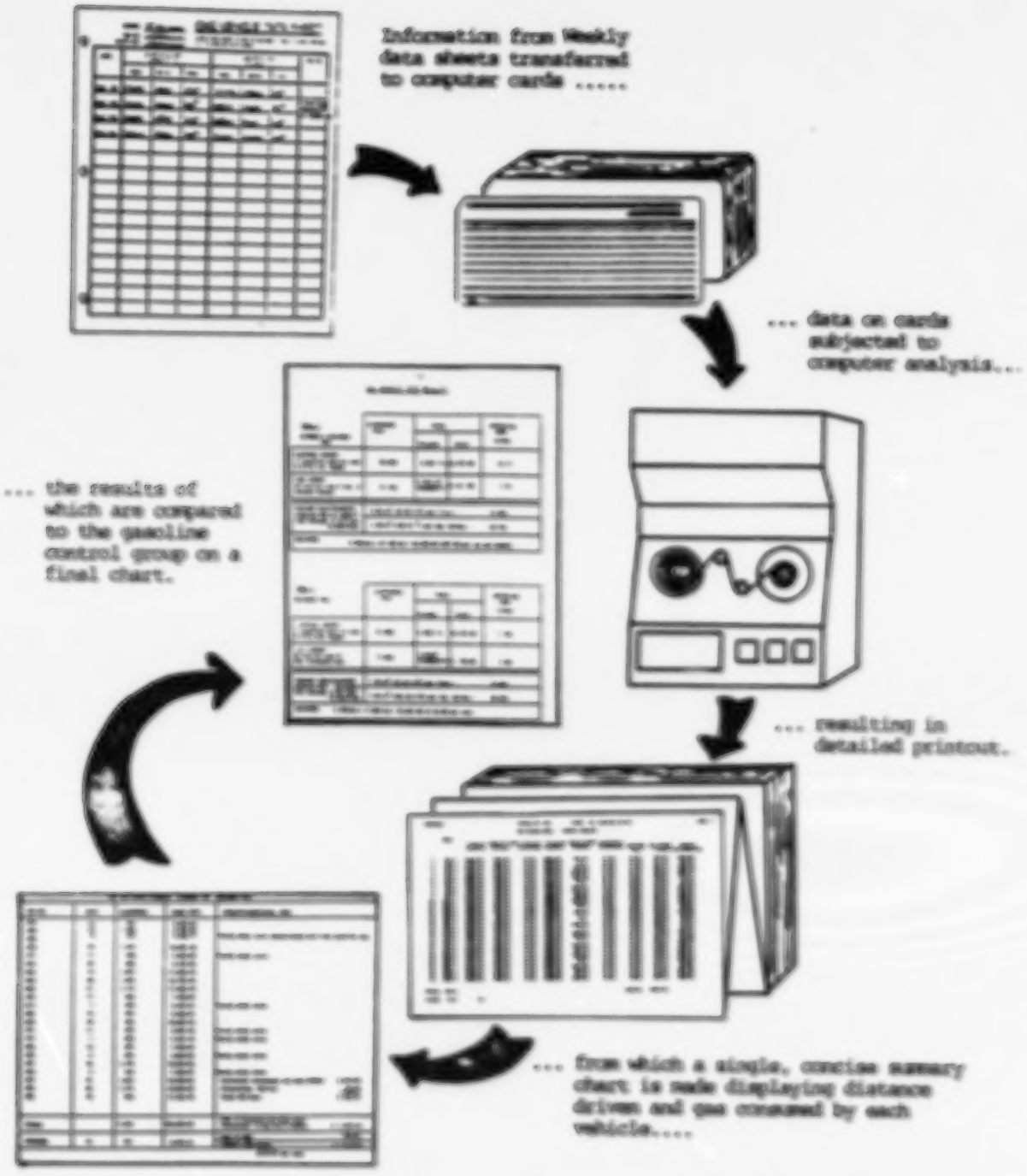
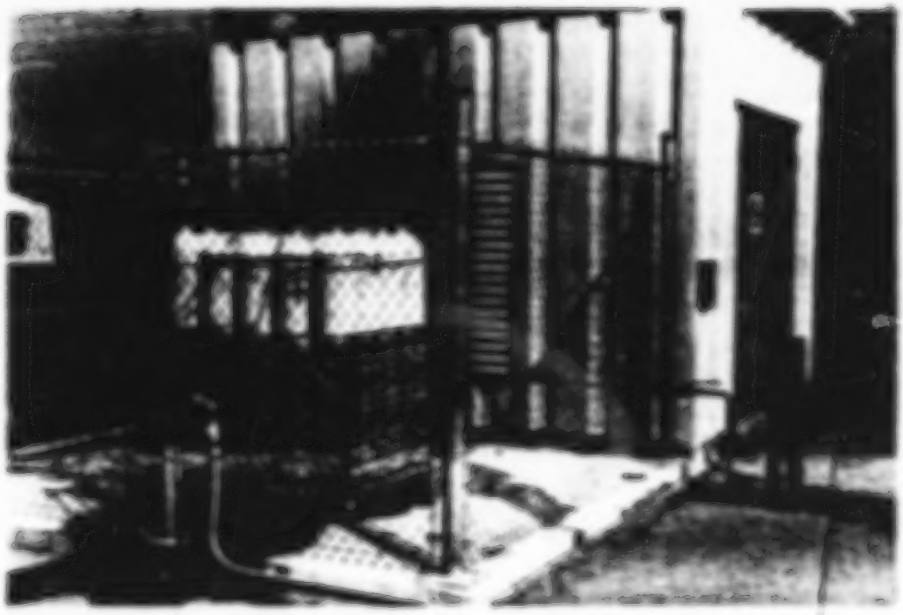

Information from Weekly data sheets transferred to computer cards .....
... data on cards subjected to computer analysis...
... resulting in detailed printout.
... from which a single, concise summary chart is made displaying distance driven and gas consumed by each vehicle.....
... the results of which are compared to the gasoline control group on a final chart.

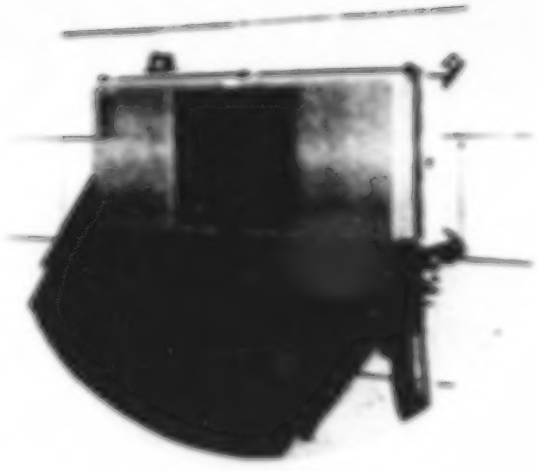
Figure 4/ Data Reduction Procedure

...eight of these GMC 6y [illegible] U.S.A. vehicles are now running on natural gas with four more having added shortly.

Figure 7/ Compressor Utility Truck for Construction and Maintenance



Pressure, temperature and flow sensor location



Computer and Display Unit (price, cubic metre throughput and total price)

Figure 6/ Euromatic CNG Flowmeter

POOR

QUALITY

ORIGINAL